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XXI. *An Attempt to explain a Difficulty in the Theory of Vision, depending on the different Refrangibility of Light. By the Rev. Nevil Maskelyne, D. D. F. R. S. and Astronomer Royal.*

Read June 18, 1789.

THE ideas of sight are so striking and beautiful, that we are apt to consider them as perfectly distinct. The celebrated EULER, taking this for granted, has supposed, in the Memoirs of the Royal Academy of Sciences at Berlin for 1747, that the several humors of the human eye were contrived in such a manner as to prevent the latitude of focus arising from the different refrangibility of light, and considers this as a new reason for admiring the structure of the eye; for that a single transparent medium, of a proper figure, would have been sufficient to represent images of outward objects in an imperfect manner; but, to make the organ of sight absolutely complete, it was necessary it should be composed of several transparent mediums, properly figured, and fitted together agreeable to the rules of the sublimest geometry, in order to obviate the effect of the different refrangibility of light in disturbing the distinctness of the image; and hence he concludes, that it is possible to dispose four refracting surfaces in such a manner as to bring all sorts of rays to one focus, at whatever distance the object be placed. He then assumes a certain hypothesis of refraction of the differently refran-

refrangible rays, and builds thereon an ingenious theory of an achromatic object-glass, composed of two meniscus glasses with water between them, with the help of an analytical calculation, simple and elegant, as his usually are.

He has not, however, demonstrated the necessary existence of his hypothesis, his arguments for which are more metaphysical than geometrical; and, as it was founded on no experiment, so those made since have shewn its fallacy, and that it does not obtain in nature. Moreover, which is rather extraordinary, it does not account, according to his own ideas, for the very phenomenon which first suggested it to him, namely, the great distinctness of the human vision, as was observed to me, many years ago, by the late Mr. JOHN DOLLOND, F. R. S. to whom we are so much obliged for the invention of the achromatic telescope; for the refractions at the several humors of the eye being all made one way, the colours produced by the first refraction will be increased at the two subsequent ones instead of being corrected, whether we make use of NEWTON'S or EULER'S law of refraction of the differently refrangible rays.

Thus EULER produced an hypothetical principle, neither fit for rendering a telescope achromatic, nor to account for the distinctness of the human vision; and the difficulty of reconciling that distinctness with the principle of the different refrangibility of light discovered by Sir ISAAC NEWTON remains in its full force.

In order to go to the bottom of this difficulty, as the best probable means of obviating it, I have calculated the refractions of the mean, most, and least refrangible rays at the several humors of the eye, and thence inferred the diffusion of the rays, proceeding from a point in an object, at their falling upon

upon the retina, and the external angle which such coloured image of a point upon the retina corresponds to.

I took the dimensions of the eye from M. PETIT, as related by Dr. JURIN; and, the specific gravities of the aqueous and vitreous humors having been found to be nearly the same with that of water, and the refraction of the vitreous humor of an ox's eye having been found by Mr. HAWKSBEЕ to be the same as that of water, and the ratio of refraction out of air into the crystalline humor of an ox's eye having been found by the same accurate experimenter to be as 1 to ,68327, I took the refraction of the mean refrangible rays out of air into the aqueous or vitreous humor, the same as into water, as 1 to ,74853, or 1,33595 to 1; and out of air into the crystalline humor as 1 to ,68327, or 1,46355 to 1. Hence I find, according to Sir ISAAC NEWTON's two theorems, related at Part II. of Book I. of Optics, p. 113. that the ratio of refraction of the most, mean, and least refrangible rays at the cornea should be as 1 to ,74512, ,74853 and ,75197; at the fore-surface of the crystalline as 1 to ,91173, ,91282, and ,91392; and at the hinder surface of the crystalline as 1 to 1,09681, 1,09550, and 1,09420.

Now, taking with Dr. JURIN 15 inches for the distance at which the generality of eyes in their mean state see with most distinctness, I find the rays from a point of an object so situate will be collected into three several foci, *viz.* the most, mean, and least refrangible rays at the respective distances behind the crystalline ,5930, ,6034, and ,6141 of an inch, the focus of the most refrangible rays being ,0211 inch short of the focus of the least refrangible ones.

Moreover, assuming the diameter of the pencil of rays at the cornea, proceeding from the object at 15 inches distance,

to be $\frac{1}{3}$ th of an inch in a strong light, which is a large allowance for it, the semi-angle of the pencil of mean refrangible rays at their concurrence upon the retina will be $7^{\circ} 12'$, whose tangent to the radius unity, or ,1264 multiplied into ,0211 inch, the interval of the foci of the extreme refrangible rays, gives ,002667 inch for the diffusion of the different coloured rays, or the diameter of the indistinct circle upon the retina. Now, I find, that the diameter of the image of an object upon the retina is to the object as ,6055 inch to the distance of the object from the center of curvature of the cornea; or the size of the image is the same as would be formed by a very thin convex lens, whose focal distance is ,6055 inch, and consequently a line in an object which subtends an angle of $1'$ at the center of the cornea will be represented on the retina by a line of $\frac{1}{5678}$ th inch. Hence the diameter of the indistinct circle on the retina before found, ,002667 will answer to an external angle of $,002667 \times 5678' = 15' 8''$, or every point in an object should appear to subtend an angle of about $15'$, on account of the different refrangibility of the rays of light.

I shall now endeavour to shew that this angle of ocular aberration is compatible with the distinctness of our vision. This aberration is of the same kind as that which we experience in the common refracting telescope. Now, by computation from the tabular apertures and magnifying powers of such telescopes, it is certain that they admit of an angular indistinctness at the eye of no less than $57'$; therefore the ocular aberration is near four times less than in a common refracting telescope, and consequently the real indistinctness, being as the square of the angular aberration, will be 14 or 15 times less in the eye than in a common refracting telescope, which may be easily allowed to be imperceptible.

Moreover,

Moreover, Sir ISAAC NEWTON has observed, with respect to the like difficulty of accounting for the distinctness with which refracting telescopes represent objects, that the erring rays are not scattered uniformly over the circle of diffipation in the focus of the object-glass, but collected infinitely more densely in the center than in any other part of the circle, and in the way from the center to the circumference grow continually rarer and rarer, so as at the circumference to become infinitely rare; and by reason of their rarity are not strong enough to be visible, unless in the center and very near it.

He farther observes, that the most luminous of the prismatic colours are the yellow and orange, which affect the sense more strongly than all the rest together; and next to these in strength are the red and green; and that the blue, indigo, and violet, compared with these, are much darker and fainter, and compared with the other stronger colours, little to be regarded; and that therefore the images of the objects are to be placed not in the focus of the mean refrangible rays, which are in the confine of green and blue, but in the middle of the orange and yellow, there where the colour is most luminous, that which is in the brightest yellow, that yellow which inclines more to orange than to green.

From all these considerations, and by an elaborate calculation, he infers, that though the whole breadth of the image of a lucid point be $\frac{1}{33}$ th of the diameter of the aperture of the object-glass, yet the sensible image of the same is scarce broader than a circle whose diameter is $\frac{1}{230}$ th part of the diameter of the aperture of the object-glass of a good telescope; and hence he accounts for the apparent diameters of the fixed stars as observed with telescopes by astronomers, although in reality they are but points.

The

The like reasoning is applicable to the circle of diffipation on the retina of the human eye; and therefore we may lessen the angular aberration, before computed at $15'$, in the ratio of 250 to 55, which will reduce it to $3' 18''$.

This reduced angle of aberration may perhaps be double the apparent diameter of the brightest fixed stars to an eye disposed for seeing most distinctly by parallel rays; or, if short-sighted, assisted by a proper concave lens; which may be thought a sufficient approximation in an explication grounded on a diffipation of rays, to which a precise limit cannot be assigned, on account of the continual increase of density from the circumference to the center. Certainly some such angle of aberration is necessary to account for the stars appearing under any sensible angle to such an eye; and if we were, without reason, to suppose the images on the retina to be perfect, we should be put to a much greater difficulty to account for the fixed stars appearing otherwise than as points, than we have now been to account for the actual distinctness of our sight.

The less apparent diameter of the smaller fixed stars agrees also with this theory; for the less luminous the circle of diffipation is, the nearer we must look towards its center to find rays sufficiently dense to move the sense. From Sir ISAAC NEWTON's geometrical account of the relative density of the rays in the circle of diffipation, given in his system of the world, it may be inferred, that the apparent diameters of the fixed stars, as depending on this cause, are nearly as their whole quantity of light.

In farther elucidation of this subject let me add my own experiment. When I look at the brighter fixed stars, at considerable elevations, through a concave glass fitted, as I am short-sighted, to shew them with most distinctness, they appear

to me without scintillation, and as a small round circle of fire of a sensible magnitude. If I look at them without the concave glass, or with one not suited to my eye, they appear to cast out rays of a determinate figure, not exactly the same in both eyes, somewhat like branches of trees (which doubtless arise from something in the construction of the eye) and to scintillate a little, if the air be not very clear. To see day objects with most distinctness, I require a less concave lens by one degree than for seeing the stars best by night, the cause of which seems to be, that the bottom of the eye being illuminated by the day objects, and thereby rendered a light ground, obscures the fainter colours blue indigo and violet in the circle of dissipation, and therefore the best image of the object will be found in the focus of the bright yellow rays, and not in that of the mean refrangible ones, or the dark green, agreeable to NEWTON's remark, and consequently nearer the retina of a short-sighted person; but the parts of the retina surrounding the circle of dissipation of a star being in the dark, the fainter colours, blue, indigo, and violet, will have some share in forming the image, and consequently the focus will be shorter.

The apparent diameter of the stars here accounted for is different from that explained by Dr. JURIN, in his Essay on distinct and indistinct vision, arising from the natural constitution of the generality of eyes to see objects most distinct at moderate distances, and few being capable of altering their conformation enough to see distant objects, and among them the celestial ones, with equal distinctness. But the cause of error, which I have pointed out, will affect all eyes, even those which are adapted to distant objects.

If this attempt to shew the compatibility of the actual distinctness of our sight with the different refrangibility of light

light shall be admitted as just and convincing, we shall have fresh reason to admire the wisdom of the Creator in so adapting the aperture of the pupil and the different refrangibility of light to each other, as to render the picture of objects upon the retina relatively, though not absolutely, perfect, and fitted for every useful purpose; “where,” to borrow the words of our religious and oratorical philosopher DERHAM, “all the “glories of the heavens and earth are brought and exquisitely “pictured.”

Nor does it appear, that any material advantage would have been obtained, if the image of objects on the retina had been made absolutely perfect, unless the acuteness of the optic nerve should have been increased at the same time; as the *minimum visibile* depends no less on that circumstance than the other. But that the sensibility of the optic nerve could not have been much increased beyond what it is, without great inconvenience to us, may be easily conceived, if we only consider the forcible impression made on our eyes by a bright sky, or even the day objects illuminated by a strong sun. Hence we may conclude, that such an alteration would have rendered our sight painful instead of pleasant, and noxious instead of useful. We might indeed have been enabled to see more in the starry heavens with the naked eye, but it must have been at the expence of our daily labours and occupations, the immediate and necessary employment of man.

I shall only mention farther, and obviate an objection to the diffusion of the rays upon the retina by the different refrangibility of light. It may be said, that the ocular aberration, being a separate cause from any effect of the telescope, should subsist equally when we observe a star through a telescope as when we look at it with the naked eye; and that therefore the

fixed stars could not appear so small as they have been found to do through the best telescopes, and particularly by Dr. HERSCHEL with his excellent ones. To this I answer, that the ocular aberration, which is proportional to the diameter of the pupil when we use the naked eye, is proportional to the diameter of the pencil of rays at the eye when we look through a telescope, which being many times less than that of the pupil itself, the ocular aberration will be diminished in proportion, and become insensible.

